MINERAL CONTENT OF LEAVES CLUE TO WHITE OAK SITE QUALITY

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Erratum

The literature citations referred to in footnote 2, page 2 should be (1) and (2) instead of (2) and (4).

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Raymond F. Finn[1]

Trees require adequate quantities of certain elements for proper nutrition and growth. Where essential mineral elements are deficient or lacking in forest soils, tree growth will be retarded. Only minute amounts of some mineral elements are needed, but several, including nitrogen and phosphorus, are required in relatively large quantities.

Previous investigators reported that the amount of nitrogen and phosphorus in physiologically mature leaves of certain tree species, including white oak (*Quercus alba* L.), is closely related to the amount of these elements available in the soil (6, 7). They also found that white oak grew more rapidly after forest plots were treated with nitrogenous fertilizers. By means of foliar analysis, they set tentative standards for judging the ability of certain soils in the Northeast to supply nitrogen.

The objectives of the study reported here were: (1) To find out how growth of white oak is related to the concentration of nitrogen, calcium, potassium, and phosphorus in the leaves; and (2) to find out how soil characteristics, topography, and aspect in southeastern Ohio are related to the concentration of these elements in white oak leaves.

CLIMATE AND SOILS

The 33 plots sampled in this study are located in Athens, Hocking, and Vinton Counties in southeastern Ohio. The area is unglaciated, with rolling to steeply hilly topography. The average annual precipitation is 40 inches, mostly in the form of rain, and is well distributed throughout the year. The highest monthly average precipitation occurs in March and July. The average number of days without killing frosts is about 170 (10).

The forests of southeastern Ohio grow on the same type of gray-brown podzolic soils that support most of the forests of the Central Hardwood Region. All of the plots in this study were located within the Muskingum-Wellston-Zanesville soil association. The Muskingum soils are poorly developed; the organic layer and the parent material can be distinguished, but other horizons are absent or indistinct. The Muskingum series is ordinarily found on the steeper slopes in contrast to the Wellston and Zanesville

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1/ Forester, Buckeye Research Center.

series which occupy gentler topography. The Wellston profile is well developed; the A_2, B_1, and B_2 horizons can be clearly distinguished in addition to the organic horizons and the parent material. The development of the Zanesville series is still more advanced, but this series provided few observations in this study. All of these soils are derived from sandstones, siltstones, or shales. Fragments of parent material are commonly found in all horizons of the Muskingum soils, but usually only in the deeper horizons of the other soil series (11).

FORESTS

Hardwoods form most of the forest of this region. The oak-hickory type predominates. Extensive, even-aged stands occur as a result of clear-cutting 60 or more years ago for charcoal. Stands sampled in this study range in age from 30 to 120 years.

Site quality for white oak is closely associated with topography and exposure. The poorer sites are found on ridgetops and upper slopes, the best sites on the bottoms and the north and east lower slopes (1). A variety of tree species can be found in any stand, but the oaks predominate in numbers and volume. White oak is an important species commercially.

HOW THE STUDY WAS MADE[2/]

Leaf samples were collected late in August 1949 from dominant and codominant white oak trees on 33 one-fifth-acre circular plots. Samples were collected from a total of 129 trees, at least 3 on each plot. A ladder and pruning pole were used to get leaf samples from shorter trees; a 12-gauge shotgun was used to dislodge leaves from taller trees. About 25 leaves were taken from each sample tree. They were taken from the south side of the upper crown where it was exposed to full sunlight. All collecting was done between the hours of 9 a.m. and 3 p.m. to avoid differences that commonly occur in the mineral composition of leaves due to large differences in light intensity. Only physiologically mature leaves, free from galls and other blemishes, were collected.

After the leaves were air-dried in the laboratory, the petioles were removed and the remaining tissue was ground in a Wiley Mill. The samples were then oven-dried to constant weight at 70° C. Composite plot samples were obtained by combining equal weights of oven-dried leaf material from each tree sampled within the plot. The oven-dried composite plot samples were analyzed for total nitrogen, calcium, potassium, and phosphorus. The chemical analyses are described in detail in the Appendix.

2/ Soil and stand data were taken from the original data used in two publications listed in literature citations (2) and (4).

FOLIAR NITROGEN: Related chiefly to site index and soil depth

It has been shown in previous studies using nitrogenous fertilizers that the amount of available nitrogen in the soil is reflected by the amount of nitrogen in tree leaves (7). The present study, using natural differences in site quality as fertility levels, shows that site-quality changes are also reflected in the foliar nitrogen concentrations. The fact that trees grow more rapidly when nitrogenous fertilizers are applied and also on sites where higher nitrogen levels are found indicates that nitrogen in itself is an important factor in determining the ability of land to grow trees.

Site Index

Site index, as used in this study, is the height of dominant and codominant white oak trees at age 50 years and is a measure of the ability of the forest land to grow white oak. Site index is commonly used to compare growth rates between sites. The regression of white oak site index, as determined by Gaiser and Merz (3), on plot-slope position and percent foliar nitrogen when considered jointly was highly significant. Plot-slope position considered independently was highly significant and the added effect of foliar nitrogen was significant.3/ The regression is shown in figure 1 as a family of site-index curves with slope position and percent nitrogen in the leaves as the independent variables.

In this study, site index increased as distance from a ridge-top increased and as foliar nitrogen increased. Nitrogen content of the leaves ranged from 1.62 percent of dry weight to 2.57 percent with an average of 1.92 percent. Site index ranged from 50 to 73, and the average was 59. The white oak leaves, on the average, contained less nitrogen than the 2.2 percent Mitchell and Chandler considered indicative of the minimum amount of available soil nitrogen needed to produce average growth of white oak in New York State (7). However, white oak leaves from lower slope plots in this study did contain 2.2 percent or more nitrogen and these plots had the highest site indices.

As an approximation, after the effect of distance from the ridge is removed, each 0.1 percent increase in foliar nitrogen corresponds to about a 1-foot increase in site index for the range of the nitrogen concentrations encountered.

3/ Highly significant and significant indicate a probability of 1 chance in a 100 and 1 chance in 20 respectively that the obtained regression was due to chance.

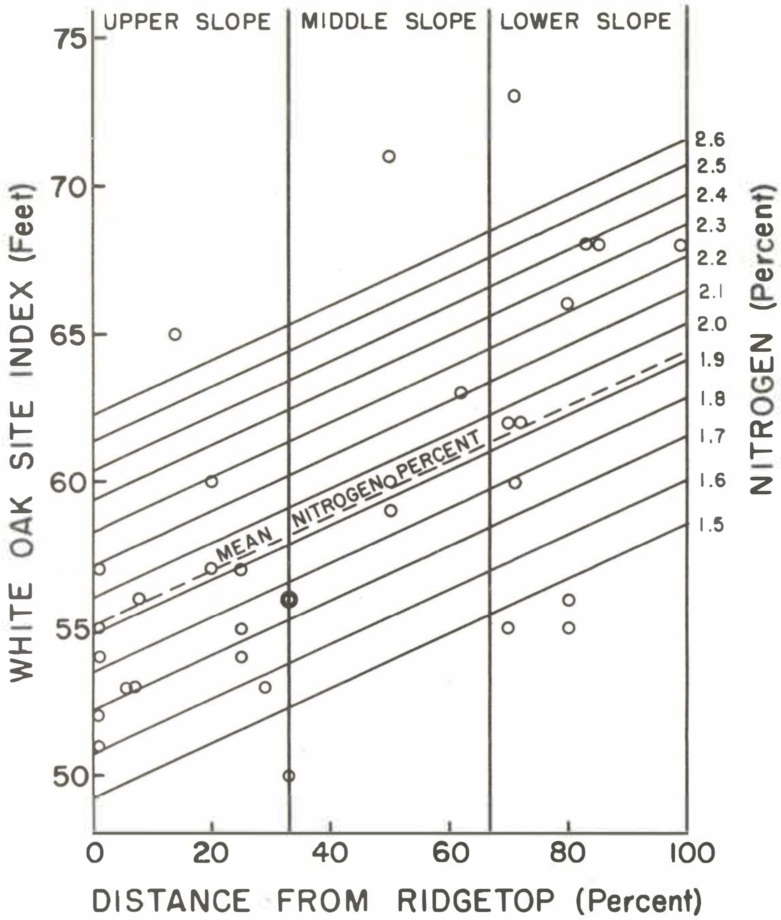

Figure 1.--Relation of white oak site index to distance from ridge and to foliar nitrogen.

A and B Soil Horizon Thickness

Foliar nitrogen was found to be closely related to A_2 soil horizon thickness. No relationship was found between foliar nitrogen and the thickness of the A_1 or B_1 horizons. However, because the A_2 accounted for 80 percent of the total A horizon thickness, a highly significant relationship between foliar nitrogen and total A horizon thickness was found (fig. 2).

It is not surprising that the A_1 soil horizon thickness, when considered alone, does not measurably affect nitrogen availability. The average thickness of the A_1 was only 1.1 inches and varied from 0 to 3.2 inches; the A_2 averaged 5.7 inches with a range from 0 to 13.7 inches. Although there were more roots 1/4-inch in diameter and smaller (considered to be important in absorption) per inch of depth in the A_1 horizon, the A_2 was much thicker and so contained a greater total number of such roots (2). For this reason the A_2 horizon better reflects the amount of available nitrogen.

The thickness of the A horizon in southeastern Ohio is confounded with topography and exposure. Thickest A horizon soils are usually found on the lower slopes because soil moisture conditions are usually more favorable on these slopes and organic matter decomposes more rapidly. The same environmental characteristics favor both increase in thickness of the A horizon and release of nitrogen in available form from organic matter. That the level of foliar nitrogen is associated with the physical nature of the surface soil profile partly explains why a good estimate of the growth rate of white oak can be made from soil characteristics.

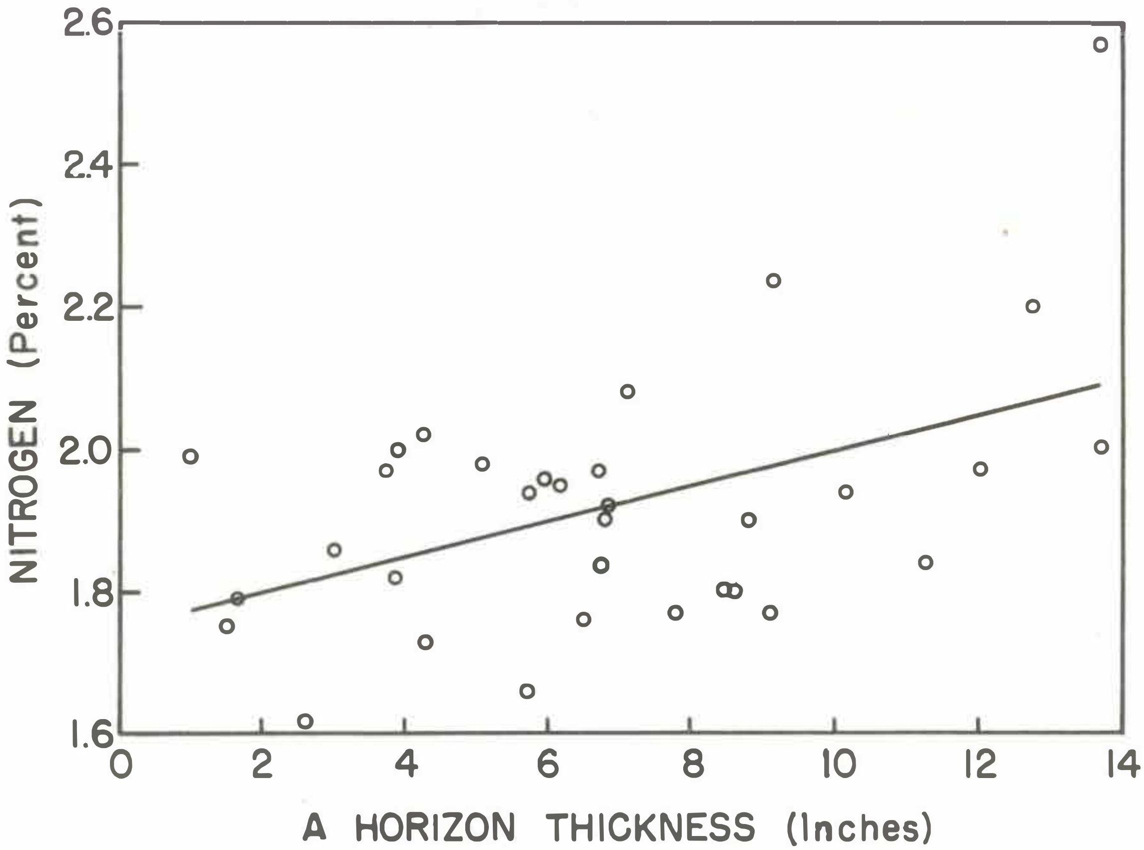

Figure 2.--Relation of foliar nitrogen to A horizon thickness.

Other Data Not Conclusive

Moisture equivalents[4/] of the A horizon in the plots ranged from 13 to 29 percent and averaged 23 percent. There was an indication that foliar nitrogen tends to decrease directly as moisture equivalent percentage increases; data for the lower moisture equivalent percentages were too scanty to be conclusive.

4/ Moisture equivalent is the amount of water left in the soil after it has been subject to a centrifuging force of 1,000 times that of gravity.

Neither stand density nor age was found to be related to foliar nitrogen in this study. These results are logical since high or low densities and young or old stands can, with equal probability, be found on good or poor sites. Foliar nitrogen differences associated with either stand age or stand density probably are not perceptible because of the much greater differences associated with changes in site quality.

The amount of available soil nitrogen, as measured by the concentration of this element in leaves, was not found to be related to exposure, even though site index is affected by this factor (1). Probably soil depth changes, which often are independent of aspect, are sufficient to obscure most of the effect of aspect on amount of foliar nitrogen.

Although Mitchell and Chandler (7) found a high degree of correlation between the percent foliar nitrogen and the diameter growth of white oak, the lack of controlled conditions in the current study made it impossible to confirm this relationship.

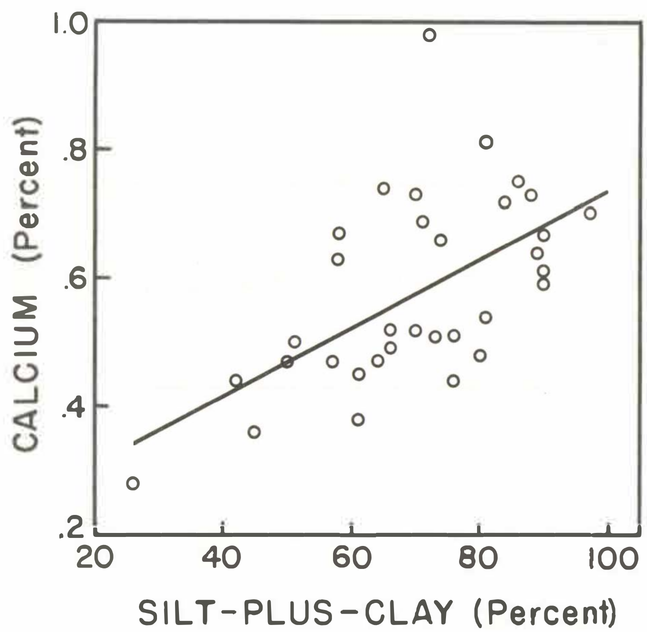

Figure 3.--Relation of foliar calcium to silt-plus-clay in the A horizon.

FOLIAR CALCIUM: Reflects soil texture and root concentration

Foliar calcium increased as the percent silt-plus-clay increased in the A soil horizons. This linear regression is highly significant and is shown in figure 3. The average foliar calcium concentration was 0.58 percent with a range extending from 0.28 percent to 0.98 percent. The silt-plus-clay content averaged 70 percent with a low of 26 and a high of 97 percent.

Foliar calcium also increased as the concentration of roots in the A soil horizon increased. Figure 4 shows this relationship plotted as a linear regression that was significant. The average concentration of roots, 1/4-inch in diameter and smaller, is 80 per vertical square foot. Numbers ranging from 14 to 130 roots per square foot indicate the wide variation in root concentrations.

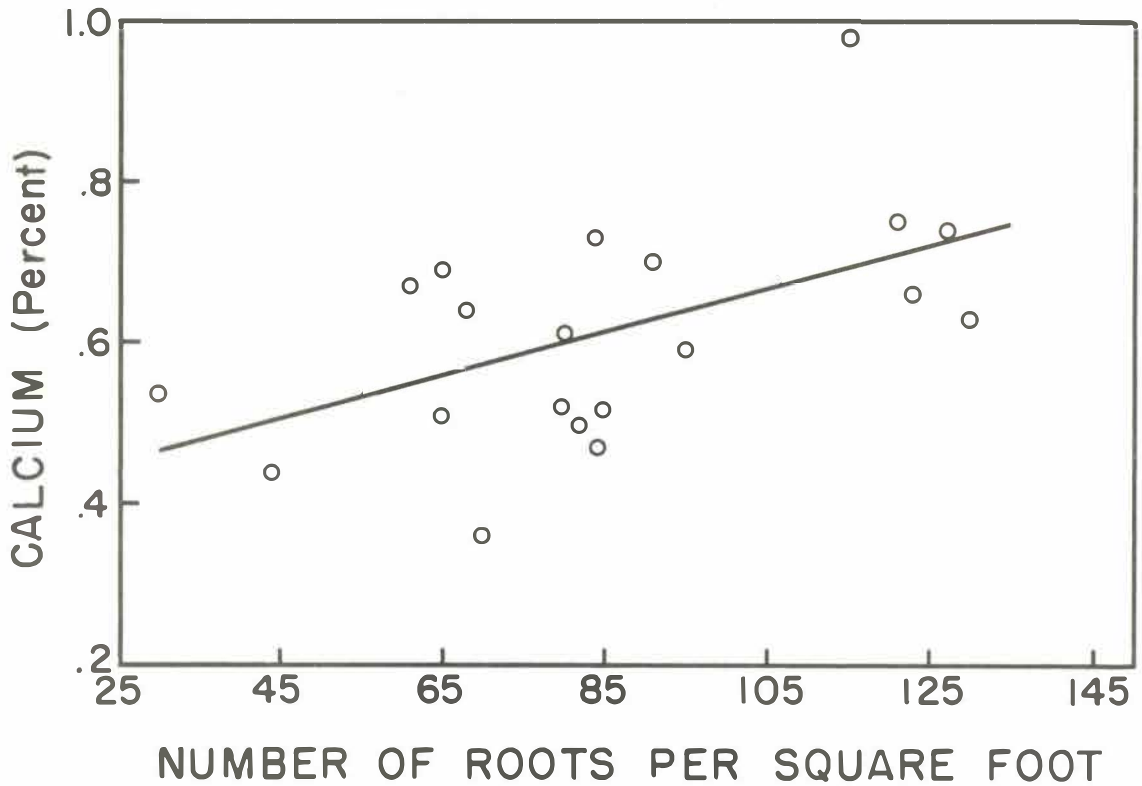

Figure 4.--Relation of foliar calcium to root concentrations in the A horizon.

In spite of the fact that foliar calcium is related both to percent silt-plus-clay and to the concentration of roots in the A soil horizon, the concentration of roots could not be shown to be correlated with percent silt-plus-clay. It may be inferred from this that root concentration is independent of percent silt-plus-clay in the A soil horizon. However, since the foliar calcium is closely related to the amount of silt-plus-clay in the A horizon and to root concentration there, the amount of silt-plus-clay must influence the quantity of calcium held by the soil colloids. Mere depth of soil is less important than the ability of the soil to hold the calcium against leaching.

The amount of calcium in white oak leaves is less in this study than that reported for this species by other workers. They usually report more than 1 percent but less than 2 percent. The soils encountered in this study are derived largely from sandstones, siltstones, and/or shales. Since a deficiency of calcium is probably due to a lack of the element rather than to its presence in unavailable form (5), the inference can be made that the soil supplying capacity for calcium is low due to the nature of the parent material from which the soil is derived.

Calcium is strongly absorbed by the soil colloids. Being present in relatively small quantities, most of it may be assumed to be strongly absorbed. The soil solution is probably very low in calcium and the roots may have to be in actual contact with the clay particles before calcium can be absorbed. This may explain in part why foliar calcium is influenced by these two independent factors: Amount of silt-plus-clay and concentration of roots in A horizon.

That calcium is held strongly in the A horizon is evidenced by the relative unimportance of the thickness of the subsoil on foliar calcium. Where calcium in available forms in the soil solution is abundant, one would expect that the root concentration would have a less pronounced effect on calcium absorption and hence on foliar calcium since this was found to be true for nitrogen, phosphorus, and potassium.

The plot having the highest foliar calcium concentration was on a soil containing particles of lime that effervesced on addition of dilute hydrochloric acid and likewise the lowest foliar calcium concentration was found for the plot with the highest percentage of sand.

In spite of the low foliar calcium encountered, it could not be shown in this study that growth of white oak was markedly affected. It is possible that the requirements of white oak for calcium are very modest.

FOLIAR POTASSIUM AND PHOSPHORUS: Not related to site or soil

Foliar potassium averaged 1.42 percent; the lowest value was 1.01 percent and the highest 1.76 percent. The concentration of foliar phosphorus ranged from 0.12 to 0.27 percent and averaged 0.17 percent.

Both potassium and phosphorus are essential for satisfactory plant growth. Any great deficiency should adversely affect growth. The concentrations encountered in the present study apparently are sufficient for normal white oak growth. Variations in foliar concentrations were not found to be related to white oak site index, or to diameter growth. The concentrations found here are about the same as the concentrations reported for average to good stands in the Northeast. Apparently the concentration of these elements in white oak leaves is little affected by root concentrations, soil thickness, soil texture, exposure, and position on the slope within the range of conditions in this experiment. It is reasonable therefore to conclude that the forest soils in southeastern Ohio for the most part are capable of supplying sufficient potassium and phosphorus for average white oak growth.

SUMMARY

Nitrogen, calcium, potassium, and phosphorus contents of the sample white oak leaves were determined by chemical analysis. The percentage of nitrogen in the leaves was found to be related to the site quality of the land as expressed by site index, thickness of the A horizon, and position on the lower slopes. Factors not found to be related were thickness of the B_1 soil horizon, stand age, density, diameter growth, and aspect.

Foliar calcium was found to be related to the silt-plus-clay content of the A soil horizon and to the concentration of roots in the A soil horizon. Factors not found to be related to foliar calcium were thickness of the soil horizons, site index, stand age, stand density, diameter growth, aspect, and position on the slope.

Foliar potassium and phosphorus were not found to be related to any of the above factors. No interrelationship could be shown between any combination of the four elements.

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APPENDIX

Nitrogen Analysis

The oven-dried composite plot samples were analyzed for total nitrogen by a modification of the micro-Kjeldahl method described by Pregl (8). Duplicate samples (50 to 80 milligrams) were digested with 1 milliliter of sulfuric acid containing 1 gram of salicylic acid per 30 ml. of sulfuric acid and a knife point of a dry mixture of 1 part potassium sulfate to 3 parts of mercuric sulfate. This colorless solution was cooled and distilled water was added to bring the salts into solution. The ammonia produced from the nitrogen in the leaves was distilled in a micro-Kjeldahl unit after adding 7.5 ml. of 30 percent sodium hydroxide containing 5 percent sodium thiosulfate. The distillate was collected in an excess of N/100 hydrochloric acid. The excess of hydrochloric acid was titrated with N/100 sodium hydroxide and the percentage of nitrogen present in the leaves was calculated.

Digestion for Potassium and Calcium Analysis

Four grams of the composited plot samples were treated with 10 ml. of concentrated nitric acid and gently heated after the initial reaction subsided. Following cooling, 10 ml. each of 1:1 nitric acid and 72 percent perchloric acid were added and the solution was heated until it became colorless. The colorless solution was evaporated to dryness and ignited to dull red heat to remove ammonia. Five ml. of 1:1 hydrochloric acid and 10 ml. of water were added and low heat was applied to dissolve the salts. The resulting solution was filtered into a volumetric flask and made up to volume. Aliquots of these solutions were used to determine total potassium and calcium.

Potassium Analysis

A 5 ml. aliquot was transferred to a 15 ml. centrifuge tube which was placed on a water bath until the contents had been evaporated to approximately 1 ml. To this was added 1 drop of 0.01 percent methyl orange solution and 1:17 acetic acid until the solution was neutral. Two ml. of a solution containing 0.3 grams of sodium cobaltinitrate were slowly added to the neutralized solution which was swirled and placed in a refrigerator at 5^{o} C. for 3 hours, swirling several times during this period. The upper walls of the tube were washed with 1/2 ml. of water and centrifuged at 3000 r.p.m. for 10 minutes and drained for 5 minutes. Two 3 ml. portions of 70 percent ethyl alcohol were introduced into the tube at the same time stirring the precipitate. The contents were again centrifuged and drained. This was repeated until the washings were clear. Five ml. of water was added and the precipitate was brought into solution on a boiling water bath. The contents were transferred

to a 25 ml. volumetric flask and the color was developed by adding 2 ml. of a 2 percent choline hydrochloride solution and 2 ml. of a 4 percent sodium ferrocyanide solution. After 10-15 minutes the percent transmission was read using a Model B, Beckman Spectrophotometer set at wave length 580 mu. The amount of potassium present in the sample was read from a previously calibrated chart and the percent potassium in the leaves was calculated.

Calcium Analysis

The calcium concentration in an aliquot sample was determined spectrometrically using a Beckman flame attachment in conjunction with a Beckman Model B Spectrophotometer. A calibration chart was prepared and from this the quantity of calcium (p.p.m.) in the sample was read. These data were used to determine the percentage of calcium in the leaves.

Phosphorus Analysis

Total phosphorus was determined colorimetrically according to a method of Snell and Snell (9). Four grams of each composite plot sample was treated with 10 ml. of concentrated nitric acid and gently heated after the initial reaction subsided. Following cooling, 10 ml. each of 1:1 nitric acid and 72 percent perchloric acid were added and the solution was heated until it became colorless. The colorless solution was evaporated to dryness and ignited to dull red heat. Five ml. of 1:1 hydrochloric acid and 10 ml. of water were added and low heat was applied to dissolve the salts. The resulting solution was filtered into a 50 ml. volumetric flask and made up to volume. An aliquot part was transferred to a 25 ml. volumetric flask, diluted to 15 ml. with water, and 2.5 ml. of 60 percent perchloric acid was added. To this was added 0.8 ml. of 1-ammino-2-naphthol-4-sulfonic acid reagent followed by 2 ml. of filtered 5 percent ammonium molybdate solution. The solution was made to volume and percent transmission was read after 15 minutes at 750 mu. on a Beckman Model B Spectrophotometer. Milligrams of phosphorus were read from a previously prepared calibration chart and the percentage of phosphorus in the leaves was determined.

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